# Department of Defense
# Legacy Resource Management Program

PROJECT NUMBER (10-143; 12-143)
MIPR NUMBER (W9132T-10-2-0033; W9132T-12-2-0033)

**Development and utilization of a landscape scale GIS model to identify potential bat habitat features in the Desert Southwest: Identification and Status of Sensitive Bat Habitat Resources**

**Publication 2 – Diamond 2014**

BAT CAVERN ROOST CHARACTERISTICS ACROSS THREE DEPARTMENT OF DEFENSE INSTALLATIONS IN SOUTHERN ARIZONA

JOEL M. DIAMOND*

*Arizona Game and Fish Department, Wildlife Contracts Branch, Phoenix, AZ 85086 (JMD)*
*Present address of JMD: Arizona Game and Fish Department, Wildlife Contracts Branch, 5000 West Carefree Highway, Phoenix, AZ 85086*
**Correspondent: jdiamond@azgfd.gov*

ABSTRACT--The Department of Defense (DoD) manages over 12,690 $km^2$ of land across three installations in southern Arizona. These installations contain mountain ranges that provide cavern roosting habitat for bats. Seven former Category 2 sensitive species and one federally endangered species have the potential to occur on these three installations in roosting habitats. In order to increase the understanding of bat roosting habitat on DoD managed lands in southern Arizona, we designed a study focused on locating and defining the characteristics of roosts. We utilized historical records and topographic maps to locate potential roosting habitat across these three installations. Once located we used internal and external roost surveys to determine bat use. We located 153 caverns and determined that 44 provided bat roosting habitat. We found bat use by six of the seven target species. Bat species use was associated with elevation while bat use type was linked to cavern size. Larger caverns were more likely to serve as day roost and combined day and night roosts.

INTRODUCTION--Many bat populations in North America are declining (Stebbings 1980, McCracken 1988, Richter et al.1993, Tudge 1994 and Altingham 1996). Of 43 bat species in the United States, five are listed as federally endangered and 19 are candidates for listing (Code of Federal Regulations 1991). Declines in bat species may be attributed, in part to loss of habitat due to increased human activity (Humphrey and Kunz 1976). This decline in bat use of native habitats has led to an interest in identifying and protecting bat roosts. It is unclear what role military owned lands plays in the management of bat habitat and potential recovery of local bat species.

The Department of Defense (DoD) manages over 12,690 $km^2$ of land across three installations in southern Arizona. These installations are managed by the United States Marine Corps, U.S Air Force, and U.S. Army. The Barry M. Goldwater Range-West (BMGR-West), Barry M. Goldwater Range-East (BMRG-East), and Yuma Proving Ground (YPG) are vast installations characterized by broad valleys bordered by steep mountain ranges. Mountain ranges on DoD installations have the potential to provide cavern roosting habitat for bats. Seven former Category 2 (C2) sensitive species and one federally endangered species have the potential to occur on these three installations in roosting habitats (Adams 2003). The distribution of bat roosting habitat is poorly understood across these three DoD installations. Given, that continued and future military training activities on these installations are dependent on minimizing operational and training impacts on any federal and state sensitive species, it is imperative that the actual and potential bat roosting habitat on these installations is fully understood.

The loss and modification of bat roosting habitats are major factors contributing to the putative decline of many bat populations (Tuttle and Taylor 1994; Adams 2003). The primary source of habitat loss is likely increased human disturbance (Pierson 1989; Brown and Berry 1991; Pierson and Brown 1992; Sherwin et al. 2000). More than half of bat species found in the United States regularly use natural (caves) and anthropogenic (abandoned mines) caverns as roosts (Tuttle and Taylor 1994; Keeley and Tuttle 1999; Bogan 2000; Adams 2003). The importance of cavern roosts for bats lies in the potential to provide a variety of roosting types, including maternity, hibernacula, day, night, and interim roosts (Sherwin et al. 2000). Maternity roosts provide a secure location for females to give birth and rear young throughout the summer season (Humphrey 1975; Kunz 1982). Hibernacula provide a winter refuge (Raesly and Gates 1986; Johnson et al. 1998; Kuenzi et al. 1999). Day roosts are used by non-reproductive individuals of both sexes, while night roosts are utilized by all bats regardless of reproductive status as a place to rest and digest their prey between foraging bouts (Lacki et al. 1994; Kerth et al. 2001). Night roosts are generally in different locations than day roosts and are used primarily at dawn and dusk (Anthony et al. 1981). Interim roosts are used in the spring before the young are born and again in the fall before retreating to hibernation roosts (Twente 1955; Dobkin et al. 1995). Specific roost requirements, particularly internal roost microclimate, are necessary for bat recruitment, and each species has a specific range of appropriate roosting temperatures that is advantageous to different life phases and thus, survival (Kunz 1982). Understanding the species and roost types that occur on these three DoD installations in southern Arizona will aid the DoD's goals in preventing declines in local bat species and better manage bat habitat on military managed property.

Seven bat species have the potential to utilize cavern roosting habitats on DoD installations in southern Arizona. These bat species are listed as species of special concern by the Arizona Game and Fish Department and the Department of the Interior. These species were the focus of a DoD Species at Risk assessment in Arizona and New Mexico as part of a DoD funded legacy project. These seven species are; lesser longed-nosed bat (*Leptonycteris curasoae*: LEYE), pallid bat (*Antrozous pallidus*: ANPA), cave myotis (*Myotis velifer*: MYVE), Yuma myotis (*Myotis yumanensis*: MYYU), Mexican free-tailed bat (*Tadarida brasiliensis*: TABR), Townsend's big-eared bat (*Corynorhinus townsendii*: COTO) and California leaf-nosed bat (*Macrotus californicus*: MACA). The lesser long-nosed bat is a federally-listed endangered species in the U.S. and Mexico and regularly uses cavern roosts to the south of these DoD installations (Arita 1991, Cockrum 1991, Fleming et al. 1993, Wilkinson and Fleming 1996, Cole and Wilson 2006, Morales-Garza et al. 2007, Shull 1988; SEDESOL 1994). Pallid bats have been observed foraging on these installations and regularly use cavern roosts throughout their range (Adams 2003; Lewis 1987; Diamond pers. comm.). Cave myotis have been captured at water sites on these installations and are known to roost in cavern habitat on and adjacent to these installations (Fitch et al. 1981; Diamond pers. comm.). Yuma myotis is generally associated with crevice and cavern roosts adjacent to open water and has been captured at water sites on these installations (Cockrum et al. 1996). Mexican free-tailed bats are also known to roost in cavern habitats adjacent to these DoD installations (Hoffmeister 1986). Townsend's big-eared bats are cavern obligate species and are also known to roost adjacent to these DoD installations (Cockrum *et al.* 1996). California leaf-nosed bats have been captured at water sites on these installations and regularly use cavern roosts (Hoffmiester 1986). These seven species of special concern all have the potential to occur on these DoD installations. In order to increase the understanding of the bat roosting habitat on DoD managed lands in southern Arizona we designed a study focused on determining roost distribution and defining the characteristics of those roosts.

METHODS--*Study Area*--Diurnal bat roost surveys were conducted within each of the three DoD military installations in southwestern Arizona. These include two areas of the Barry M. Goldwater Range (BMGR-East and BMGR-West) and Yuma Proving Grounds (YPG). Each installation is divided into sections specifically for aerial systems training including live fire training and ground maneuvers. The installations together cover approximately 12,690 $km^2$ of the Sonoran Desert's Lower Colorado River Subdivision. Steep mountain ranges are surrounded by expansive, sparsely vegetated valleys and wide, shallow washes. The elevation ranges from approximately 80-800 m. Average rainfall is less than 8 cm and summer temperatures can exceed 44°C. Dominant vegetation includes creosotebush (*Larrea tridenta*), white bursage (*Ambrosia dumosa*), foothills palo verde (*Parkinsonia microphylla*), mesquite (*Prosopis* spp.), ironwood (*Olneya tesota*) and various cactus species.

BMGR-East and BMGR-West lies within Pima, Maricopa and Yuma counties, and extends from Yuma eastward toward Gila Bend, Arizona. The Range is bounded to the south by Mexico and Cabeza Prieta National Wildlife Refuge, to the north by Interstate 8 and a mix of private and public properties, and to the east by the Tohono O'odham Nation and Bureau of Land Management lands. Elevations range from below 61 m on western portions of the range to 1,128 m in the Sand Tank Mountains (BMGR 2007). Temperatures on BMGR can range rarely from below 0°C to 49°C, with a range-wide average annual rainfall of approximately 12.7 cm. The Lower Colorado River Subdivision of the Sonoran Desert is the predominating vegetative community and is characterized by extremely drought-tolerant plant species such as creosote, bursage, paloverde and cacti (e.g., *Cylindropuntia* spp. and saguaro: *Carnegiea gigantea*) (Brown 1994). The broad, flat and sparsely vegetated desert plains of the entire BMGR installation are dissected by numerous incised washes that harbor ironwood, smoketree (*Psorothamnus spinosa*), catclaw acacia (*Acacia greggii*), velvet mesquite (*Prosopis velutina*), ocotillo (*Fouquieria splendens*) and numerous shrub species.

YPG lies within La Paz and Yuma counties near Yuma, Arizona and totals approximately 3,450 $km^2$ (fig. 1). The YPG installation is also dominated by the Lower Colorado River Subdivision of the Sonoran Desert and contains the same basic vegetative communities described under BMGR. The broad, flat and sparsely vegetated desert plains of YPG are dissected by numerous incised washes that harbor ironwood, smoketree, acacia, mesquite and numerous shrub species (Brown 1994). More elevated hills and mountain slopes contain vegetation consisting of Arizona Upland Subdivision of the Sonoran Desert with sotol (*Dasylirion wheeleri*), cacti and agave (*Agave* spp.). The range of elevation on YPG is from sea level to 878 m. The average temperatures on YPG are between 16°C and 30°C with average annual rainfall of 8.8 cm.

Cavern habitat survey efforts were focused within the Trigo, Tank and Muggins mountains on YPG; the Mohawk and Granite mountains, Crater Range and White Hills on

BMGR-East; Mohawk, Gila, Copper and Tinajas Altas mountains and the Wellton Hills on BMGR-West. We used historical data, topographic maps and on the ground surveys to locate any actual or potential cavern habitat within these mountain ranges. We conducted internal roost surveys of cavern sites when safety could be assured and used external methods at those deemed unsafe for internal survey.

Internal surveys required the entrance of personnel and equipment into cavern sites, necessitating the continual assessment of potential hazards while the internal surveys were being conducted. During internal surveys, we conducted roost counts, mine structure assessment, and microclimate measurements. Surface and ambient temperatures and relative humidity were recorded at the cavern entrance and subsequently every 15 m; at the working face (terminus of the cavern habitat); and at the location of any evidence of bat use (including roosting bats, bat carcass, guano, urine staining, discarded insect parts). Roost temperatures were collected by focusing a digital thermometer on the roof above bat sign and likely reflect the actual microclimate (substrate temperature) at ceiling heights or at the cavern features where bats may be located. Roost relative humidity and cavern air temperature were recorded with a digital sling psychrometer and digital thermometer. Cavern structural characteristics such as the geological nature of the substrate, the presence of crevices and fissures, and the location and volume of stopes, raises, and winzes were also recorded. These surveys were conducted by an experienced bat biologist also trained and experienced in abandoned mine entry. This is the most efficient approach to cavern assessment for bat use. All internal surveys followed the USFWS white nose syndrome operating protocol. Each surveyor focused on the identification of bat sign, the number of individual bats, and potential hazards (e.g., surface subsidence, structural instability such as loose flakes, and vertical hazards).When safety of survey personnel was in question, we conducted external surveys of cavern features.

External surveys provided an estimate of the number of animals using a roost (Richter et al. 1993; Ludlow and Gore 2000). We used Sony Nightshot™ (Sony Corporation, Koyoto, Japan) infrared video cameras to determine bat use at cavern sites deemed unsafe for entry. Evening surveys lasted 2 consecutive hours starting at least 15 minutes before sunset. Several camera sets were placed as early as 45 minutes prior to sunset due to high illegal migrant activity in the immediate area. Video cameras were placed at inconspicuous locations within 5 m of the cavern opening for full view of the opening with a 1-m buffer zone on either side of the cavern site opening. Additional infrared light sources were placed near the cavern opening for illumination. This provided shadow elimination and full infrared lighting of 5 m both within and outside the cavern, allowing for an unimpaired observation of all bat activity near the opening. We used these internal and external cavern surveys to determine the roost distribution on the landscape and define the characteristics of roosts.

We collected several roost variables that may contribute to bat use and compared them across species and roost types observed in the field. Roost variables included; elevation, human disturbance level (low, moderate, or high) based on amount of activity observed, structural stability (low, medium, and high) of the cavern site, presence of warm air traps within the cavern site, roost height, roost width, roost length, roost volume, presence of airflow in the cavern site, number of openings into the roost, roost complexity (low, medium, or high) determined by number of openings or amount of underground areas, temperature at the roost opening, temperature at the deepest point in the roost, and the difference between the opening and deepest temperature. We analyzed these data using mixed model Analysis of variance (ANOVA) and Fisher's LSDs ($p$ = 0.05) to test for significant differences in roost characteristics among the seven species (LEYE, COTO, MACA, MYYU, MYVE, TABR, Unknown spp. and non-roosts) and three roost types (day roost, night roost, combined day and night roost and non-roosts).

RESULTS--We were able to locate and conduct internal surveys or external surveys on 153 cavern sites that were potential bat roosts across the three DoD installations. We detected roost use consistent with COTO, MACA, MYYU, MYVE, TABR, and an unknown bat species. Bat use was defined primarily by the presence of guano and culled arthropod parts. We located six COTO roosts; three day roosts, two night roosts and a single combined day and night roost. We detected nineteen MACA roosts; seven night roosts and twelve combined day and night roosts. Three MYYU roosts were detected, and all served as day roosts. We located eight MYVE roosts; six day roosts and two day and night roosts combined. Only one TABR roost was detected and it served as a day roost. We were unable to determine which bat species used seven roosts; one night roost and six day roosts. We did not find any definable bat activity in 109 of the potential roosts surveyed. We analyzed the six COTO, nineteen MACA, three MYYU, eight MYVE and seven unknown species roosts to determine which variables had significant relationships across species and roost types. We excluded the single TABR roost from the species specific analysis due to low sample size but included this roost in the roost type analysis.

Roost elevation varied significantly (mixed-model ANOVA; $F$ = 4.38; $p$ = 0.0016) across the species groups. COTO, MACA, MYYU, and MYVE roosts occurred at significantly lower elevation than both non-roost and the roosts for an unknown bat species (fig. 2). COTO roosts occurred at a mean elevation of 256m and MACA, MYYU, MYVE and unknown bat roosts occurred at 287 m, 348 m, 316 m, 440 m and 438 m, respectively. We detected no other significant differences across species groups.

We did detect two significant relationships across roost types with species groups combined. Day roosts and day and night roosts combined had significantly (mixed-model ANOVA; $F$ = 3.36; $p$ = 0.0419) higher roost volumes than night roosts and non-roosts (fig. 3). Day roosts had a mean volume of 105 $m^3$ and combined day and night roosts had a mean of 128 $m^3$. In contrast, night roosts had a mean volume of 27 $m^3$ and non-roost had a mean volume of 11 $m^3$. Day, night and non-roosts length did not differ significantly (mixed-model ANOVA; $F$ = 2.61; $p$ = 0.0603). However, combined day and night roosts were significantly (Student's t-test; $t$ = 3.41; $p$ = 0.0014) longer than all other roost types (fig. 4). Combined day and night roosts had a mean length of 33 m while day, night and non-roosts had mean lengths of 12, 8 and 8 m, respectively. We did not detect any further significant relationships between roost variables and roost types.

DISCUSSION--During the course of this study we located 44 bat roosts that serve as habitat for six bat species. We located an additional 109 cavern features that were not used by bats during the course of this study. MACA were the dominate species detected and occurred in 44% of the roosts surveyed followed by MYVE, unknown species, COTO, MYYU and TABR at 18, 16, 14, 7 and 2% of the total roosts, respectively. These cavern roosts provided roosting habitat for at least six bat species. We were able to determine species using each of these 44 bat roosts. We located 4 roosts that were used by multiple species. We did not detect any LEYE activity in any of the cavern roosts surveyed. The detection of these roost sites allowed us to determine the distribution and define the characteristics of roosts.

Our study area has the distinction of occurring in one of the most arid and hot climates in the western U.S. The six bat species found in this roosting study are adapted to this extreme climate both physiologically and behaviorally. While this study did not directly address the roosting physiology or behavior of these six bat species, it did detect some patterns of roost use related to bat physiology and behavior. Cavern habitat that was occupied by bats consisted of the largest available caverns. This occupancy based on the length of a roost was related to the type of bat activity taking place within the roost. The most complex bat activity type we detected was the combination of a day and night roosting. These combined day and night roosts occurred in caverns that had a length greater than 23 m. We detected a similar trend in roost volume. Day and combined day and night roosts only occurred in caverns with a volume greater than 66 $m^3$. While night roosts did not vary from non-roosts in length or volume. These trends in roost size are related to the physiology and behavior difference in day and night roosting bats.

Day roosts are used by non-reproductive individuals of both sexes, while night roosts are utilized by all bats regardless of reproductive status as a place to rest and digest their prey between foraging bouts (Lacki et al. 1994; Kerth et al. 2001). Night roosts are generally in different locations than day roosts and are used primarily at dawn and dusk (Kunz 1982; Anthony et al. 1981). Day roosts provide bats with a refuge from the external macro-climate that aids them in limiting water and energetic loss (Kunz 1982). Thus, a larger roost would provide a stable air mass within the roost that will moderate the macro-climate more than a small roost with a limited air mass.

The continued management of bat habitat on these three DoD installations should focus on management of these 44 known roosts. While these roosts vary in use type, magnitude and distribution they all provide bat habitat. Large sites and those with multiple use types should be at the forefront of management concern. These roosts are likely not a complete list of the roosting resources on these installations. Many more unknown roosts likely exist on this expansive landscape. Our findings indicate that bat surveys are required on all cavern features in order to determine bat use type and magnitude. Only one external variable (elevation) was associated with bat use. The negative association between bat use and elevation is likely due to the location of the primary available roosting habitat on these installations. Generally, the larger cavern habitat was located at mid-elevations on the mountain ranges. In summary, we found bats roosts on these installations in large caverns at mid-elevations.

I would like to thank M.D. Piokowski, R.M. Mixan, N. Foley and R.N. Gwinn for data collection and project help.

LITERATURE CITED

ADAMS, R. 2003. Bats of the Rocky Mountain West. Published by the University Press of Colorado, Boulder, Colorado.

ANTHONY, E.L. P, M. H. STACK AND T. H. KUNZ. 1981. Night roosting and the nocturnal time budget of the little brown bat, *Myotis lucifigus*: effects of reproductive status, prey density and environmental conditions. Oecologia 51:151-156.

ALTINGHAM, J.D. 1996. Bats Biology and Behavior. Oxford University Press.
ARITA, H.T. 1991. Spatial segregation in long-nosed bats, *Leptonycteris curasoe*, in Mexico. Journal of Mammalogy 72:706–714.
BOGAN, M. A. 2000. Western bats and mining. Proceedings of bat conservation and mining: a technical interactive forum. 14–16 November, 2000. St. Louis, Missouri.
BROWN, P. E., AND R. D. BERRY. 1991. Bats: habitat, impacts and mitigation. Plates 26–30 in R. D. Comer, P. R. Davis, S. Q. Foster, C. V. Grant, S. Rush, O. Thorne II, J. Todd, editors. Proceedings of the Thorne Ecological Institute: issues and technology in the management of impacted wildlife. Thorne Ecological Institute, Snowmass, Colorado.
BROWN, D. E. (ed.) 1994. Biotic Communities: Southwestern United States and Northwestern Mexico, University of Utah Press, Salt Lake City, Utah.
COCKRUM, E. L. 1991. The long-nosed bat, *Leptonycteris*: an endangered species in the southwest? Occ. Pap. Mus. Texas Tech University, 142:1-32.
COCKRUM, E. L., B. MUSGROVE, AND Y. PETRYSZYN. 1996. Bats of Mojave County Arizona: populations and movements. Occasional Papers 157. Lubbock: The Museum, Texas Tech University, Lubbock, Texas.
CODE OF FEDERAL REGULATIONS, Volume 50-Monday, July 15, 1991.
COLE, F. R,. AND WILSON, D. E. 2006. *Leptonycteris yerbabuenae*. Mammalian Species 797:1-7.
DOBKIN, D. S., R. D. GETTINGER, AND M. G. GERDES. 1995. Springtime movements, roost use and foraging activity of Townsend's Big-Eared Bat (*Plecotus townsendii*) in Central Oregon. Great Basin Naturalist 55(4):315–321.
FITCH, J.H., K.A. SHUMP ,JR., AND A.U. SHUMP. 1981. *Myotis velifer*. Mammalian species. American Society of Mammalogists. 149:1-5.
FLEMING, T. H., R. A. NUNEZ, AND L. S. L. STERNBERG. 1993. Seasonal changes in the diets of migrant and non-migrant nectarivorous bats as revealed by carbon stable isotope analysis. Oecologia 94:72-75.
HOFFMEISTER, D.F. 1986. Mammals of Arizona. Tucson: University of Arizona Press, Tucson, Arizona.
HUMPHREY, S.R. 1975. Nursery roosts and community diversity of Nearctic bats. Journal of Mammalogy 56:321-346.
HUMPHREY, S.R., AND T.H. KUNZ. 1976. Ecology of a Pleistoscene relict, the Western Big-eared bat (*Plecotus townsendii*), in the southern Great Plains. Journal of Mammalogy 57:470-494.
JOHNSON, S.A., V. BROCK, AND R.E. ROLLEY. 1998. Overwinter weight loss of Indiana bats (*Myotis sodalis*) from hibernacula subject to human visitation. American Midland Naturalist 139:255-261.
KEELEY, B. W., AND M. D. TUTTLE. 1999. Bats in American Bridges. Bat Conservation International, Inc., Resource publication No. 4. Austin, Texas.
KERTH, G., K. WEISSMANN, AND B. KONIG. 2001. Day roost selection in female Bechstein's bats (*Myotis bechsteinii*) a field experiment to determine the influence of roost temperature. Oecologia 126:1-9.
KUENZI, A.J., G.T. DOWNARD, AND M.L. MORRISON. 1999. Bat distribution and hibernacula use in west central Nevada. Great Basin Naturalist 59:213-220.

KUNZ, T.H. 1982. Roosting ecology of bats. Pp. 1-55, in Ecology of bats (T.H. Kunz, ed.). Plenum Press, New York..

LACKI, M.J., M.D. ADAM, AND L.B. SHOEMAKER. 1994. Observations on seasonal cycle, population patterns and roost selection in summer colonies of (*Corynorhinus townsendii virginus*) in Kentucky. American Midland Naturalist 131:34-42.

LEWIS, S.E. 1987. Low roost-site fidelity in pallid bats: associated factors and effect on group stability. Behavioral Ecology and Sociobiology. 39:335-344.

LUDLOW, M. E., AND J. A. GORE. 2000. Effects of a cave gate on emergence patterns of colonial bats. Wildlife Society Bulletin 28(1):191–196.

MCCRACKEN, G.F. 1989. Cave conservation: special problems of bats. National Speleological Society Bulletin, 51:49-51.

MORALES-GARZA, M. R., ARIZMENDI, M. DEL C., CAMPOS, J. E., MARTINEZ-GARCIA, M. AND A. VALIENTE-BANUET. 2007. Evidences on the migratory movements of the nectar-feeding bat *Leptonycteris curasoae* in Mexico using random amplified polymorphic DNA (RAPD). Journal of Arid Environments 68:248-259.

PIERSON, E. D. 1989. Help for Townsend's big-eared bats in California. Bats 7(1):5–8.

PIERSON, E. D., AND P. E. BROWN. 1992. Saving old mines for bats. Bats 10(4):11–13.

RAESLY, R.L., AND J.E. GATES. 1986. Winter habitat selection by North temperate cave bats. American Midland Naturalist 118(1):15-31.

RICHTER, A. R., S. R. HUMPHREY, J. B. COPE, AND V. BROCK. 1993. Modified cave entrances: thermal effects on body mass and resulting decline of endangered Indiana bats (*Myotis sodalis*). Conservation Biology 7:407–415.

SECRETARIA DE DESARROLLO SOCIAL (SEDESOL). 1994. Norma Official Mexicana NOM-059-ECOL-94, que determina las especies y subspecies de flora y fauna silvestres terrestres y acua´ticas en peligro de extincion, amenazadas, raras, y las sujetas a proteccio´n especial, y que establece especificaciones para su proteccio´n. Diaro Oficial de la Nacio´n 438:2–60.

SHERWIN, R.E, D. STRICKLAN, AND D.S. ROGERS. 2000. Roosting affinities of Townsend's Big-eared Bat (*Corynorhinus townsendii*) in northern Utah. Journal of Mammalogy 81(4):939-947.

SHULL, A.M. 1988. Endangered and threatened wildlife and plants; determination of endangered status for two long-nosed bats. Federal Register 53 (190):38456-3860.

STEBBINGS, R. E. 1980. An outline global strategy for the conservation of bats. Pages 173-178 in D. E. Wilson and A.L. Gardner, editors. Proceedings of the Fifth International Bat Research Conference. Publication of Texas Tech. University Press, Lubbock, Texas.

TUDGE, C. 1994. Going bats over conservation. New Scientist 141(1916):27-31.

TUTTLE, M.D. AND D.A.R. TAYLOR. 1994. Bats and mines. Resource Publication No. 3. Bat Conservation International, Austin, Texas.

TWENTE, J. W. JR. 1955. Some aspects of habitat selection and other behavior of cavern-dwelling bats. Ecology 36(4):706-732.

WILKINSON, G.S., FLEMING, T.H. 1996. Migration and evolution of the lesser long-nosed bats *Leptonycteris curasoae*, inferred from mitochondrial DNA. Molecular Ecology 5:329–339.

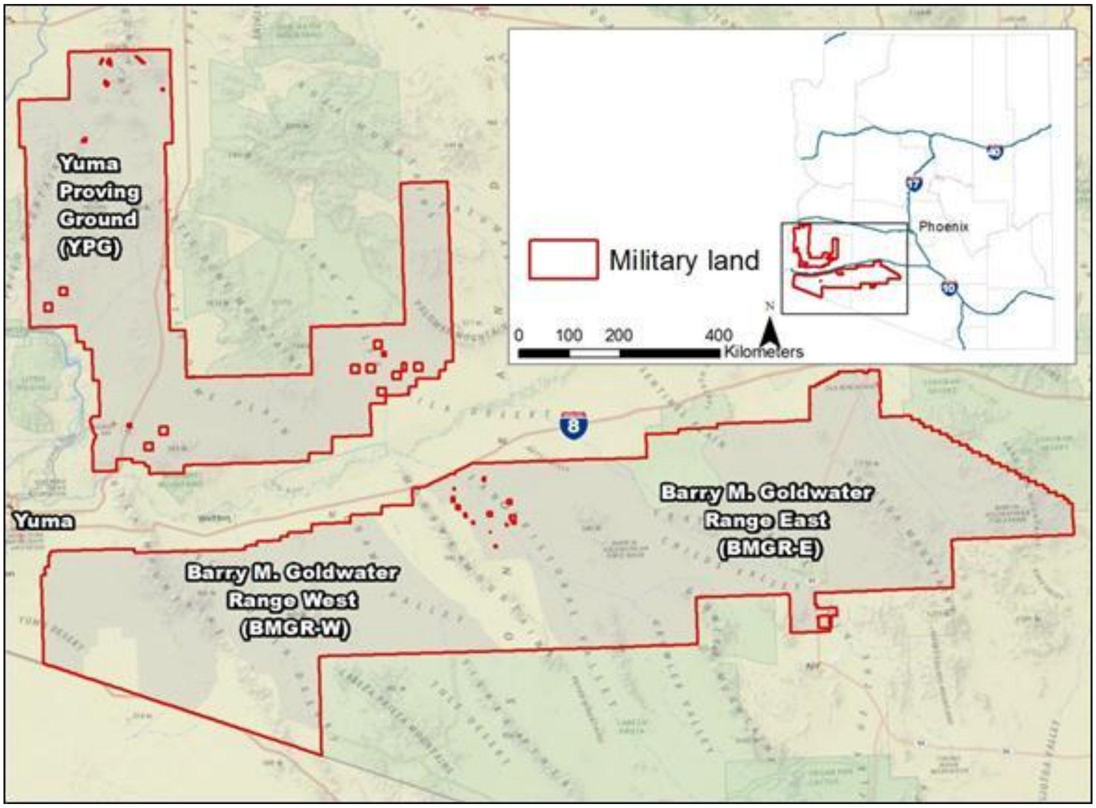


FIG 1-- Map of the three Department of Defense (DoD) installations that make up our study area.

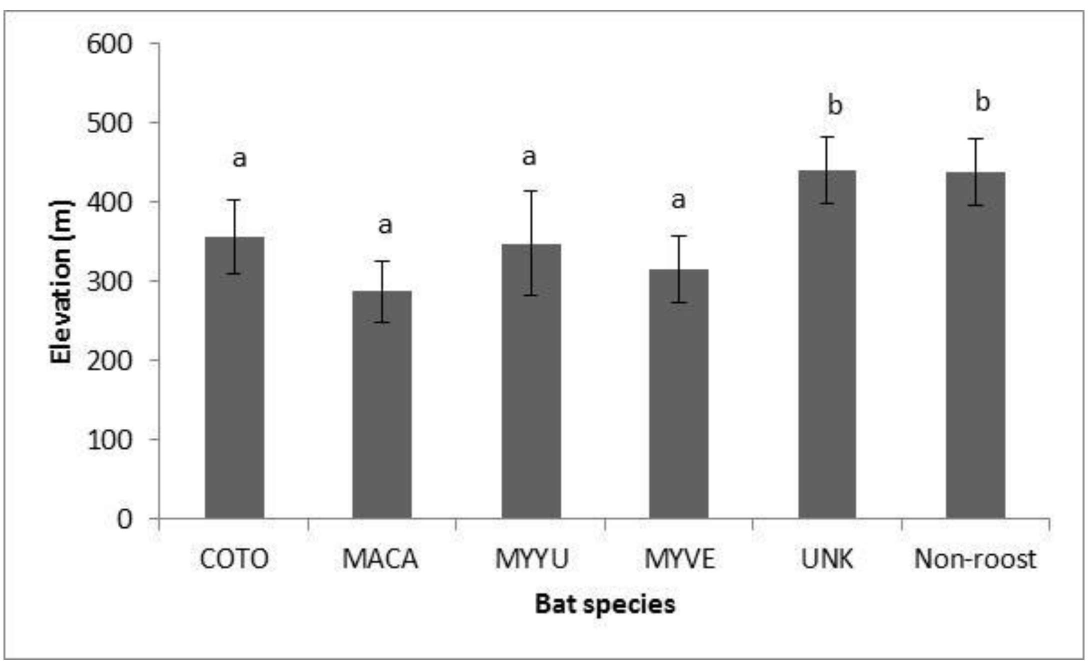


FIG 2--Elevation of bat roosts on three Department of Defense (DoD) installations in southern Arizona across five bat species groups and non-roosts. Letters indicate significant difference.

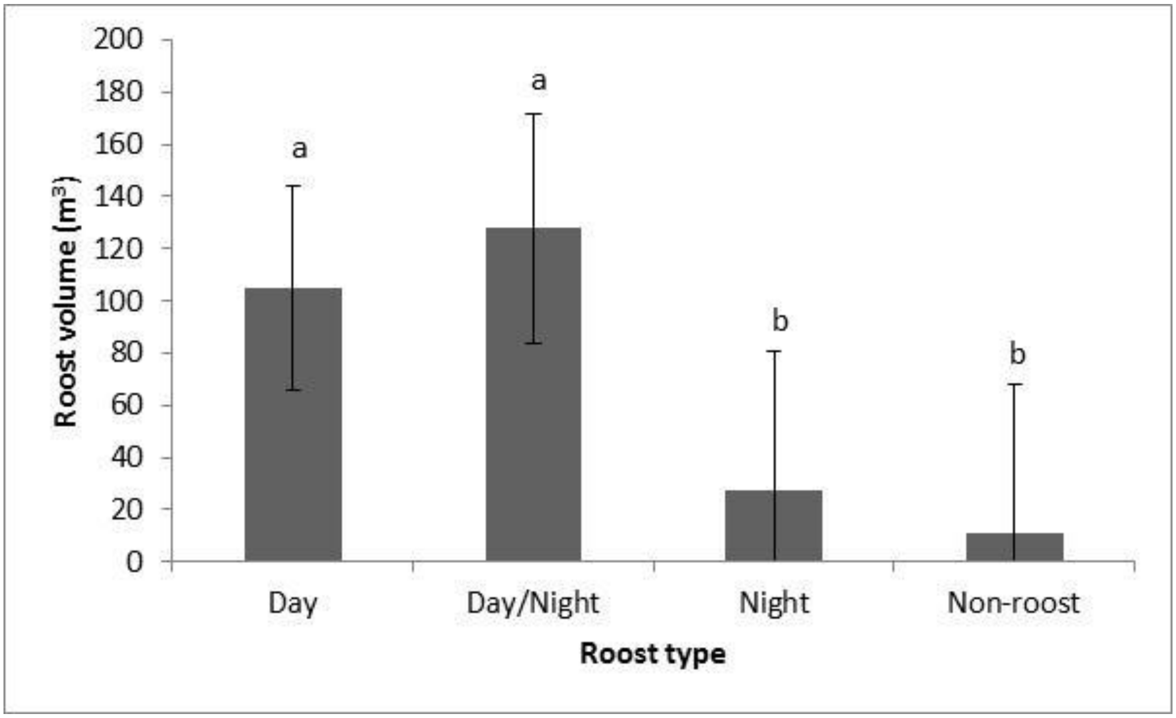


FIG 3--Roost volume of bat roosts on three Department of Defense (DoD) installations in southern Arizona across four roost types and non-roosts. Letters indicate significant difference.

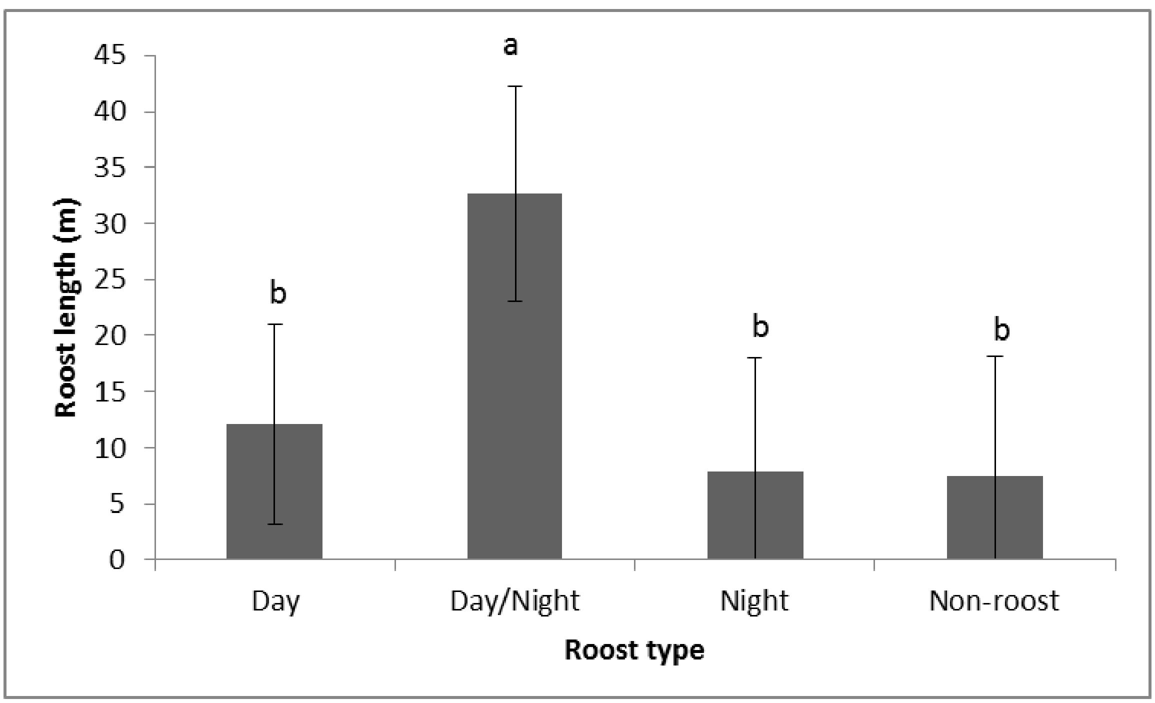


FIG 4--Roost length of bat roosts on three Department of Defense (DoD) installations in southern Arizona across four roost types and non-roosts. Letters indicate significant difference.